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MIMOSA

FINAL REPORT

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Prepared Under Contract NAS 8-20262
for
GEORGE C. MARSHALL SPACE FLIGHT CENTER
HUNTSVILLE, ALABAMA

LOCKHEED MISSILES & SPACE COMPANY
A GROUP DIVISION OF LOCKHEED AIRCRAFT CORPORATION

FOREWORD

This document is the MIMOSA Summary Digest Report, which constitutes part of the final report on the Study of Mission Modes and Systems Analysis for Lunar Exploration (MIMOSA). This study was conducted by the LMSC MIMOSA team for the George C. Marshall Space Flight Center under contract NAS 8-20262. The entire final report covers work performed from 3 January 1966 to 3 February 1967 and comprises the following parts:

- MIMOSA Summary Digest
- MIMOSA Summary Technical Report
- MIMOSA Technical Report:
  Volume I – Lunar Exploration Equipment and Mode Definition
  Volume II – Candidate Lunar Exploration Programs
  Volume III – Recommended Lunar Exploration Plan
- MIMOSA Planning Methodology:
  Volume I – Planners' Handbook
  Volume II – Exploration Equipment Data Book
  Volume III – Scientific Programs

STUDY TEAM

Company	Function
Lockheed Missiles & Space Company	Prime contractor Methodology development Scientific-program formulation Exploration-equipment definition Exploration-program planning and analysis
AiResearch Manufacturing Company	Environmental control and life support systems
Bell Aerosystems Company	Lunar flying-vehicles definition and contributions to program planning
Bendix Corporation, Aerospace Systems Division	Lunar roving-vehicles definition and contributions to scientific-program formulation
General Electric Company, Missile & space Division	Electrical-power-systems definition

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Chapter 1
INTRODUCTION

1.1 BACKGROUND

One of the major tasks of the National Aeronautics and Space Administration (NASA) is long-range planning for manned exploration of the Moon. Past effort has been devoted to specific system concepts and limited exploration eras; in this approach, the fulfillment of scientific goals was limited by the potential performance of the concepts studied. Valuable data have been collected on system feasibilities and alternate approaches to lunar exploration. However, no coordinated plan for lunar exploration has emerged that gives sufficiently detailed descriptions of the various program options available for the achievement of predetermined scientific objectives.

The MIMOSA study is an attempt to integrate existing data, with new information where applicable, into a coherent, evolutionary approach to lunar exploration for the 1970 – 1990 time frame. This approach has been formulated through the use of a planning methodology, developed and exercised during the study, that recognizes the scientific objectives as a prime forcing factor.

1.2 OBJECTIVES

The two principal objectives of the MIMOSA study were to:

- Develop a planning methodology that can provide NASA management with programmatic data, describe alternate approaches to lunar exploration, resolve planning questions, and establish preferred exploration concepts and an effective course for post-Apollo lunar activities.
- Perform an analysis of a broad spectrum of alternate lunar exploration program candidates and, with that background, formulate an overall plan for post-Apollo lunar exploration that embodies and describes several optional and attractive programs.

Chapter 2
PLANNING METHODOLOGY

The MIMOSA planning methodology supplies a set of standard procedures and criteria for organizing large amounts of planning data and provides the overall logic for generation and analysis of lunar exploration programs.

2.1 THE TOOL

Figure 2-1 illustrates the MIMOSA planning approach. The purpose of the methodology is to provide answers to specific planning questions for the evaluation of important planning factors. The following elements are provided to facilitate operation of the tool.

2.1.1 Exploration Equipment Data Book

The MIMOSA Data Book contains technical and resources data for a variety of candidate exploration equipment. The data are presented in a standard format that is designed to allow updating and introduction of new concepts, and contains information on (1) configuration, (2) performance, (3) mass statement, (4) subsystems, and (5) cost and schedule. The major equipment categories are as follows:

- Transportation systems
- Mission equipment
- Major scientific equipment
- Earth support systems

The Data Book also contains data sheets for exploration concept modes, which represent compatible equipment sets that can be used to perform a particular scientific mission.

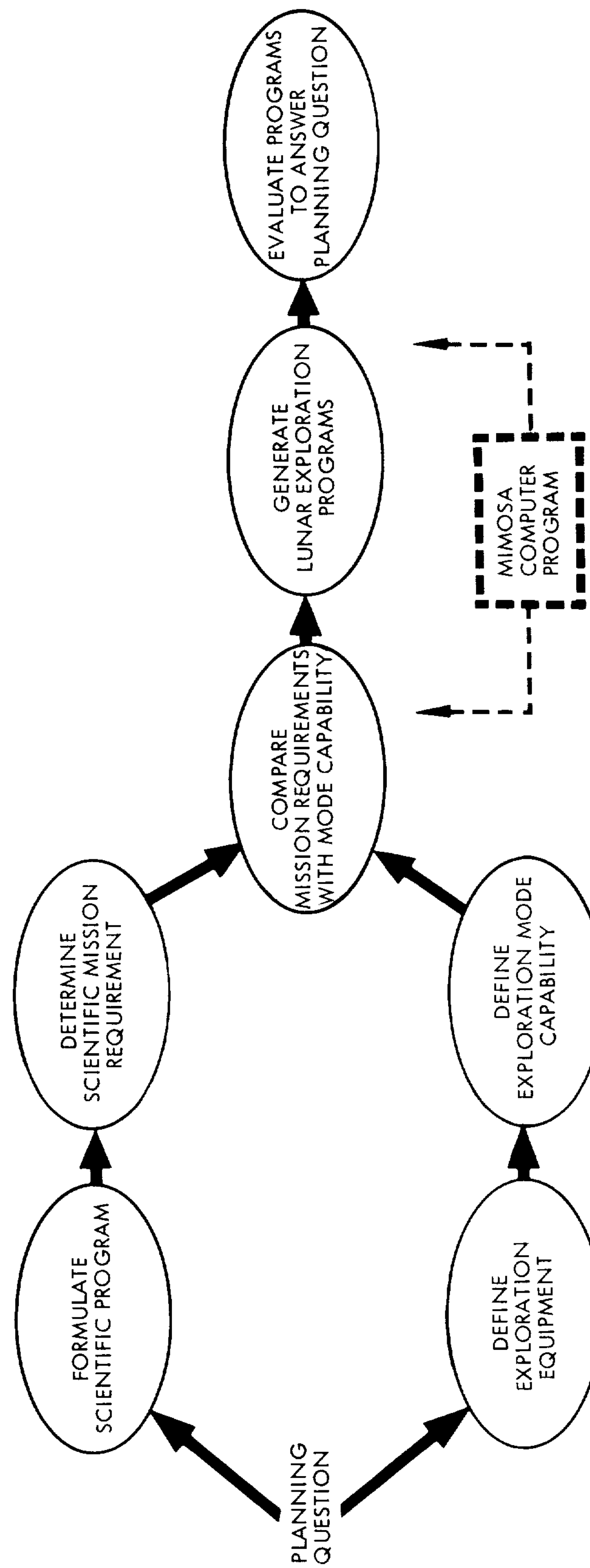


Fig. 2-1 MIMOSA Planning Methodology

2.1.2 Example Scientific Programs

Seven typical scientific programs that were developed during the MIMOSA study are provided. These scientific programs consist of lists of experiments to be performed, their priorities, associated lunar maps, preferred locales and paths to be explored, and explanatory notes for the mission planner.

Six of these programs were derived during the initial planning phase of the study to compare the efficiencies of a broad spectrum of exploration system concepts. They represent three widely different levels of scientific activity and utilize two basic approaches to exploration – locale and path. The locale approach concentrates on observation in the immediate neighborhood (about 10 km) of isolated landing points. The path approach emphasizes the distribution of scientific observations along paths joining salient features of interest.

The seventh program is the integrated scientific program that was developed during the final planning phase as part of the recommended plan for lunar exploration. This plan utilizes a limited set of exploration equipment, and the integrated scientific program is tailored to the capabilities of a prescribed evolutionary development of equipment.

All seven programs are designed to achieve the scientific goals defined at the 1965 Conference of the Space Science Board, National Academy of Sciences, held at Woods-hole, Mass.

2.1.3 Computer Program

Because the MIMOSA methodology requires the routine handling of large amounts of data, a special computer program was developed to assist the planner. The computer performs calculations, stores large amounts of data, and provides printed outputs that would require many hours of tedious labor if done by hand. However, all decision making is left to the planner.

The computer program is written for the Univac 1107/08. Approximately 15 min of machine time are required on the Univac 1108 to completely generate a typical 30-mission lunar program.

2.1.4 Planners' Handbook

Complete instructions for using the methodology are contained in the MIMOSA Planners' Handbook. A description of the computer program and detailed directions for preparing the computer input data are included in the handbook.

2.2 UTILIZATION

Utilization of the MIMOSA planning methodology involves the steps outlined in Fig. 2-1. These are as follows:

- Selection of planning question. A typical question of concern is "What Saturn V uprating is the most cost effective when used in the performance of a particular scientific program?" Relevant program assumptions must also be stipulated. Typical assumptions relate to launch constraints, funding levels, and timing of major events.
- Formulation of scientific program. Planners may select an existing scientific program or formulate others. Development of a new program requires utilization of the logic provided as part of the MIMOSA methodology. This logic permits derivation of individual experiments to answer the basic scientific questions regarding the Moon (postulated at the 1965 Woods Hole Conference of the Space Science Board of the National Academy of Sciences) by using a scientific investigation matrix that delineates the required scientific investigation by question and scientific discipline. Scope-control parameters are provided to vary the size of the scientific program. All data on experiments are given on data cards and stored in the computer.
- Determination of mission requirements. Scientific missions are planned to fulfill the demands for experimentation established by the selected scientific program. The size of a mission is normally determined with some knowledge of available equipment capability, but this knowledge is not essential. Mission

requirements are established in terms of location, traverses, experiments, manhours, mass, etc.

- Definition of exploration equipment. Exploration equipment for use in the exploration program must be defined with the specific planning question in mind. Equipment concepts may be taken from the Data Book or new concepts generated. The utilization of equipment must be such that development of a particular capability is achieved in a smooth evolutionary manner. The complete equipment set is termed an equipment evolution.
- Definition of mode capability. Within a given equipment evolution there exist equipment combinations, termed modes, that can be utilized in the performance of specific missions. A mode may be taken directly from the Data Book, or, if a suitable one cannot be found, a new mode may be formulated and its capability for sustaining a mission (payload capability, staytime, etc.) defined.
- Mission-mode comparison. Mission requirements and mode capabilities are compared and matched through an iterative process termed mission-mode matching. Approximate comparisons are performed by mission planners and the computer is used to verify the match or point out inconsistencies. In general two to three iterations of the process suffice for acceptable matching of mode capabilities with mission demands.
- Generation of exploration programs. After successful mission-mode matching of enough missions to satisfy all requirements of the scientific program, the cost and scheduling routine of the computer is used to integrate the missions into an exploration program. The computer output provides a complete description of the program in terms of cost breakdowns, equipment utilization, and development and procurement histories at program, mode, and equipment item level. This information can be summarized by planners under a standard format in an Exploration Program Summary. Again, two to three iterations are essentially adequate.
- Answer to planning question. The answer to the planning question originally posed is provided by a comparative analysis of the exploration program generated with respect to an alternate approach or a baseline program generated earlier. The analysis procedures and criteria to be used will be determined by the individual planner.

2.3 APPLICATION

The MIMOSA planning methodology enables planners to rapidly generate complete lunar exploration programs. Thus, meaningful comparative analyses can be performed to study the influence of a variety of parameters on lunar exploration programs. Important program-shaping factors can be evaluated to provide the necessary perspective and confidence for making sound decisions and commitments with full knowledge of the consequences. Typical areas of application include the following:

- Evaluation of alternate approaches to lunar exploration
- Comparison of candidate systems
- Determination of minimum cost programs
- Identification of critical development items and lead times
- Determination of efficient equipment (i.e., launch vehicles, spacecraft, mission equipment, scientific equipment, and Earth support systems) for use in future lunar exploration
- Examination of the influence of the scope of scientific effort on exploration programs
- Identification of the consequences of a changing planning environment (timing of major events, funding rate, etc.)
- Definition of resource requirements for lunar exploration

Chapter 3
A PLAN FOR LUNAR EXPLORATION

The MIMOSA planning tool was used to formulate a recommended plan for post-Apollo lunar exploration. This plan was realized in two steps. First, a broad spectrum of candidate lunar exploration programs was generated to answer a selected set of specific planning questions; analysis of these candidate programs yielded a general approach to lunar exploration and identified three critical decision points. Second, the analyses were narrowed down to a detailed investigation of the decision points using a limited set of equipment; utilization of the various equipment options available at these decision points led to three alternate exploration programs that are typical examples of implementing the exploration plan.

3.1 SPECTRUM OF CANDIDATE LUNAR EXPLORATION PROGRAMS

The first step of the planning exercise involved generation of a range of representative lunar exploration programs. A lunar exploration program results from the performance of a particular scientific program with a given equipment evolution. For generating candidate exploration programs, scientific programs and equipment evolutions were selected with a set of specific planning questions in mind. The principal scientific programs used (representing three levels of scientific activity) are summarized in Table 3-1. The selected equipment evolutions are summarized in Table 3-2, which identifies the major hardware elements of each evolution. The equipment evolutions are categorized by system capability and by the number of evolutionary steps to achieve a certain capability. Table 3-3 presents the basic planning questions together with the answers obtained from the analyses of the candidate programs.

Table 3-1

SCIENTIFIC PROGRAM SUMMARY

Scientific Program Parameter	Scientific Program		
	A	B	C
Number of locales visited	8	7	6
Total traverse distance (km)	8,500	4,800	2,400
Number of singular experiments	198	177	113
Scientific manhours	54,000	30,000	7,000
Minor scientific equipment mass (kg)	45,000	30,000	17,000
Major scientific equipment mass (kg)	110,000	50,000	14,000

The MIMOSA planning methodology was used to prepare some 30 exploration programs from particular scientific-program/equipment-evolution combinations. These programs were formulated within the following general ground rules:

- Planning period 1970 to 80's
- Maximum use of Apollo technology
- Smooth funding rate of 1 to 2 billion dollars per annum
- Saturn Apollo Applications (S/AA) equipment to be used between 1970 and 1973
- Launch rates of three to four per year from 1970 to 1977 and six to eight per year from 1978 onwards

Candidate exploration programs were analyzed in detail with a view to answering specific planning questions. A number of important parameters such as, total program cost, annual funding requirements, launch rates, lunar staytimes, scientific manhours performed, scientific mass delivered and equipment cost efficiency were examined. No one of these criteria, which reflect program accomplishment and effectiveness is absolute, and all factors must be considered. As an illustration, consider total program cost.

Table 3-2

CANDIDATE EQUIPMENT EVOLUTIONS

Evolutionary Step After Apollo	Equipment Capability Group													
	Small	Medium							Large					
	Ia	IIa	IIb	IIIa	IIIb	IIIc	IVa	IVb	Va	VIa	VIb	VIc	VId	VIe
Step 1	S/AA	S/AA	S/AA	S/AA	S/AA	S/AA	S/AA	S/AA	S/AA	S/AA	S/AA	S/AA	S/AA	S/AA
Step 2														
Saturn V Rating (%)		100	100	100	100	125	100	125	100	125	125	125	125	150
Logistics Delivery		LM/Tr	Dir. LM	LM/Tr.	LM/Tr.	LM/Tr.	LLV	LLV	LLV	LLV	LLV	LLV	LLV	LLV
Crew Delivery[a]		LOR(2)	LOR(3)	LOR(3)	LOR(3)	LOR(3)	LOR(3)	LOR(3)	LOR(3)	LOR(3)	LOR(3)	LOR(3)	LOR(3)	Dir. (3)
Shelter Crew		2	3	–	–	–	3	3	–	–	–	–	–	–
Roving Vehicle[b]		M(2)	M(3)	M(3)	M(3)	M(3)	L(3)	L(3)	L(3)	L(3)	L(3)	L(3)	L(3)	L(3)
Step 3														
Saturn V Rating (%)				100	125	125			175	125	150	175	200	150
Logistics Delivery				Dir. LM	LLV	LLV			LLV	LLV	LLV	LLV	LLV	LLV
Crew Delivery[a]				LOR(3)	LOR(3)	LOR(3)			Dir. (6)	LOR(6)	Dir. (3)	Dir. (6)	Dir. (6)	Dir. (3)
Shelter Crew				3	3	3			6	6	6	6	6	6
Roving Vehicle[b]				M(3)	M(3)	M(3)			L(3)	L(3)	L(3)	L(3)	L(3)	L(3)

(a) Number in parentheses indicates number of men on surface.
(b) M = medium (MOLAB-type) and L = large (MOBEX-type). Number in parentheses indicates crew size.

S/AA – Saturn/Apollo Applications equipment
LM/TR – LM/Truck, unmanned logistics carrier based on growth of the LM descent stage
LLV – Lunar Logistics Vehicle, unmanned logistics vehicle for direct delivery of large payloads to lunar surface
Dir LM – Direct LM, modified LM descent stage that uses inverted service module (SM) for braking and provides direct unmanned logistics delivery capability
LOR – Lunar Orbit Rendezvous techniques employed for delivery
Dir – Direct delivery

Table 3-3

CONCLUSIONS FROM CANDIDATE EXPLORATION PROGRAM ANALYSIS+

Question	Answer
PROGRAM ● What major decisions on programs and associated equipment capability should be made and when?	● Three major decision points identified regarding capability change: Continue Apollo or S/AA – Immediate Continue S/AA or Medium – 1969 to 1972 Continue Medium or Large – 1975 to 1980 ● Decision point 2 most critical for ensuring low-cost program with high scientific return
● How much can be done with Saturn Apollo Applications (S/AA) ?	● Can only perform C-level science program (7,000 manhr) at a cost of $25 billion over a period of 15 yr
SCIENCE ● What is influence of scientific program size on equipment selection and cost?	● Selection of exploration equipment is insensitive to size of scientific program. ● Total program cost is affected significantly* (See following page.) ● Largest scientific program does not fully tax the higher capability evolutions

+Answers are only valid within scope of programs investigated.

Table 3-3 (Cont.)

Question	Answer
COST • What is cost range of effective exploration programs	• *A level (55, 000 scientific manhr) approximately 24 billion • *B level (30, 000 scientific manhr) approximately $17 billion • *C level (7, 000 scientific manhr) approximately $11 billion
OPERATIONS • LOR or direct crew delivery? • Three or six-man delivery?	• LOR mode is as cost-effective as direct delivery but involves operational problems for long staytime • Three man delivery systems slightly more economical than six-man systems (approx. 10%)
EQUIPMENT • LM/Truck or direct Lunar Logistics Vehicle (LLV)? • Saturn V uprating? • Mission equipment?	• LLV is most cost effective – offers savings of 20 to 30% in total program cost • Assuming LLV, Saturn V uprating does not strongly influence cost; minimum uprating dictated by three man delivery requirement (100 to 125%) • Three-man Lunar Roving Vehicle (range approx. 800 km) is essential • Large lunar shelter required only late in program (approx 1980)

Figure 3-1 shows total program costs for the candidate exploration programs. The amount of scientific manhours achieved during a program is used as an indication of scientific activity. The basic transportation systems used in the equipment evolutions are identified in the figure.

The S/AA equipment group is limited to performance of C-level science because of limited payload and mobility capabilities. Program costs are high because of the large number of launches required. Evolutions utilizing the unmanned logistic versions of the LM/descent stage (i.e., LM/Truck) reduce program costs (compared with S/AA) particularly when used in combination with the 125% Saturn V, but large-scale scientific activity would be costly.

The lowest cost exploration programs are attained with two-step equipment evolutions that use the direct Lunar Logistics Vehicle (LLV) for logistics delivery and a single Saturn V uprating introduced after the S/AA portion of the program has been completed. Such evolutions are equally effective when used for the large or small scientific programs. These results imply that a particular equipment evolution can be selected that yields minimum program costs for the spectrum of sizes of investigated scientific programs. Commitment to the selected hardware may be made with confidence that future changes in scientific scope will not involve large cost penalties. This conclusion does not apply at very low levels of scientific activity. However, over the range of scientific effort examined in MIMOSA (3,000 to 60,000 scientific manhours), the choice of equipment is not affected by the size of the scientific program.

LLV logistics systems appear particularly attractive for exploration as they yield low-cost programs and exhibit greater flexibility to changing program demands. Using cumulative program cost per scientific manhour as an indication of exploration efficiency, this parameter is reduced by a factor of 10 in a typical program as a result of proceeding from S/AA to LLV and associated systems.

Conclusions drawn from the analysis of the candidate exploration programs are summarized in Table 3-3 in the form of answers to the planning questions that were originally posed.

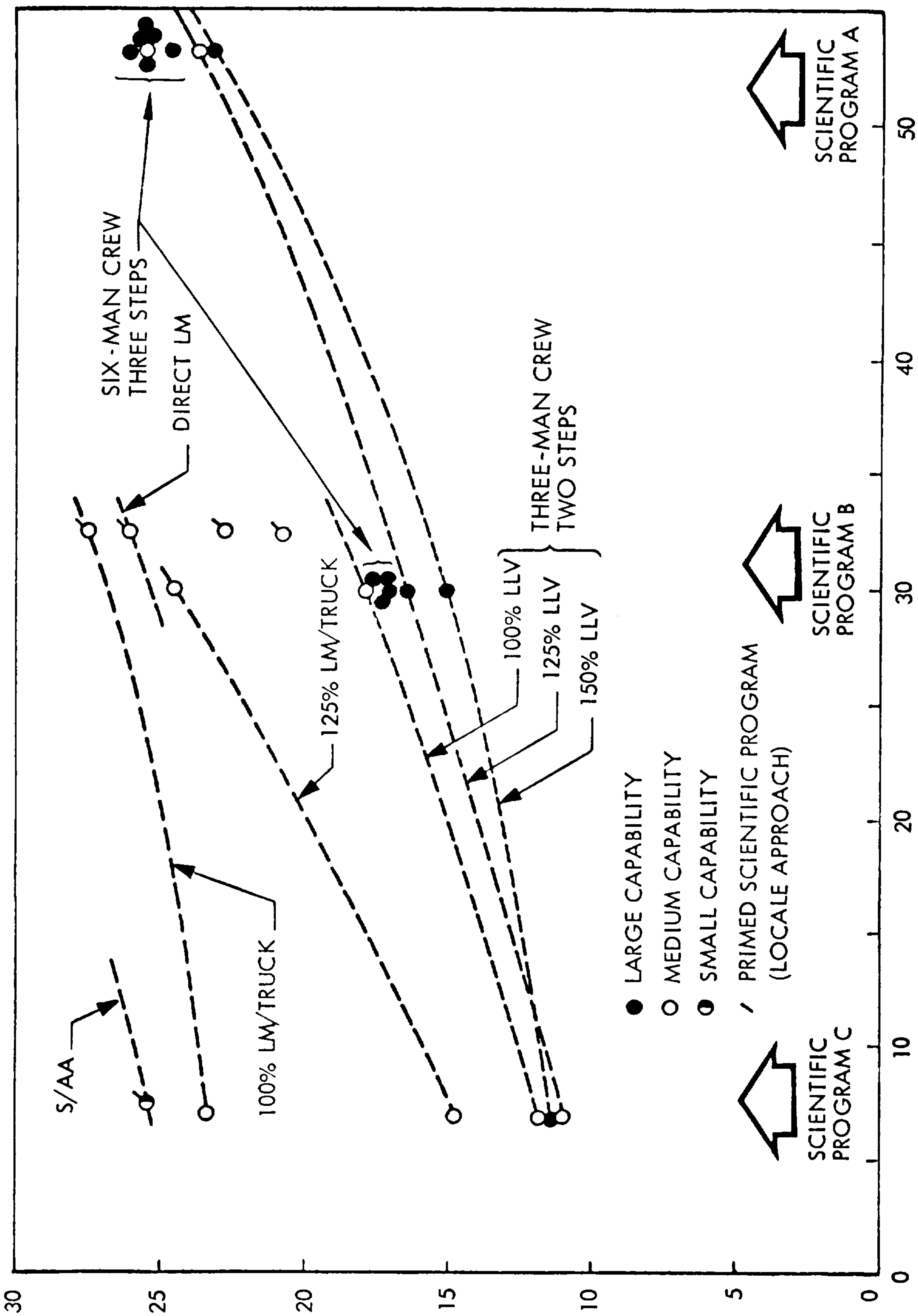


Fig. 3-1 Candidate Exploration Program Summary

In conjunction with the program analyses, it was possible to formulate the elements of a lunar exploration plan. Figure 3-2 shows this "road map" of lunar exploration, which was used as a background for evaluation of the basic planning questions. Distinct increases in equipment capabilities are visualized for the performance of various phases of the exploration program. Three decision points are identified that relate to alternate options available for changing the capability of the exploration equipment. These equipment capabilities (designated small, medium, and large) can be related to the equipment evolution groups of Table 3-2.

3.2 KEY DECISION POINTS

The second step of the planning exercise consisted of a detailed analysis of the decision points indicated in Fig. 3-2. For this analysis, specific equipment items were selected from the extensive equipment list used for generating the candidate lunar exploration programs, as representative of the three capability levels. The choice of this recommended equipment list was based on the conclusions drawn from the previous planning phase and on the need for a minimum number of equipment items to accomplish each phase of the plan.

The analysis of the three decision points was performed within the constraints of the following guidelines:

- Maintain program options for alternate equipment capabilities; in particular, ensure adaptability to any major Saturn V uprating, possibly made available for planetary program purposes
- Demonstrate potential to accommodate an increasing demand for scientific capability
- Assume no major R&D investment before FY 1970
- Plan on a funding level of less than 1.5 billion dollars per year for lunar exploration
- Ensure maximum use of developed equipment and strive for commonality
- Assume modest launch rates of three to four per year through the 1970's and six per year through the 1980's

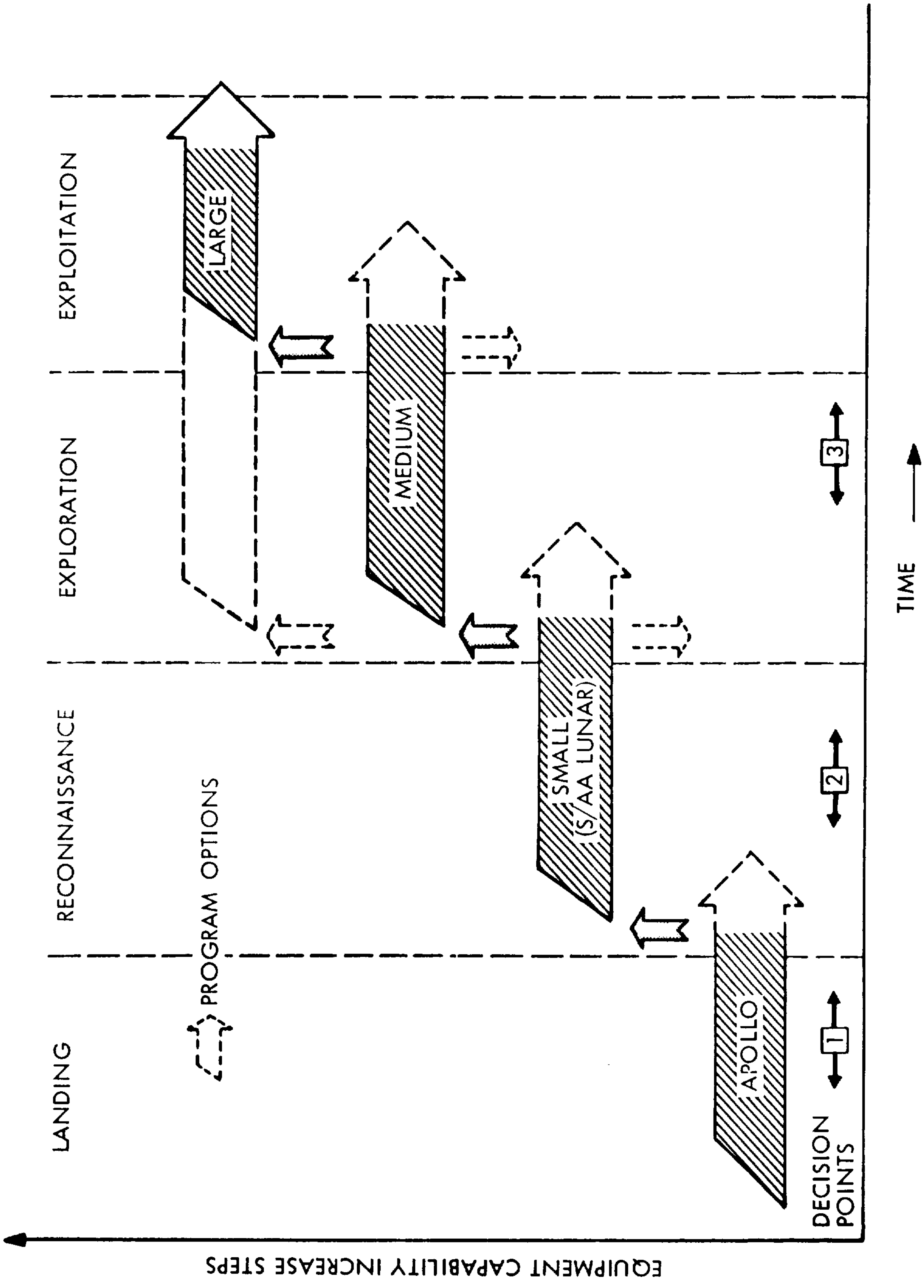


Fig. 3-2 Basic Elements of a Lunar-Exploration Plan

To fully and realistically satisfy evolutionary and increasingly demanding scientific objectives, and to accommodate the capabilities of the alternate equipment options, the concept of an integrated scientific program was developed. The integrated program embodies much of the approach and scientific content of the previously developed Scientific Programs A, B, and C. However, the total effort requested under the selected integrated program is considerably greater than that of Program A and is mainly a consequence of more agressive demands towards the end of the program for extralunar objectives associated with lunar-base activities.

Compatibility with available equipment options is maintained by allowing the scientific program scope to grow with the equipment capability. Thus, the S/AA systems are limited to locale-type operations. Introduction of the medium-level capability permits extended traverses and six-man bases. The use of large capability systems allows base activity to be conducted at the 12-man level. Each phase of the integrated program represents a balanced program in itself. At the same time, each phase forms an integral part of the total integrated program. Accomplishment of the total integrated scientific program involves about 100,000 scientific manhours and the delivery of approximately 235,000 kg of scientific equipment.

3.2.1 Decision Point 1

Decision Point 1 involves two options for continued lunar exploration, namely: continue with Apollo or introduce the S/AA systems. It was assumed that a decision to proceed with S/AA will be made in the near future. Table 3-4 summarizes the program results utilizing the NASA-recommended S/AA equipment selected for the MIMOSA study. In addition to the 400 surface scientific manhours, about 2,000 scientific manhours are performed in lunar orbit. The funding rate is about 1 billion dollars per year.

To achieve this program and to ensure a smooth transition from Apollo to S/AA, Decision Point 1 occurs in CY 1967 for a first mission in CY 1971. However, the actual commitment of funds is spread over about 4 yr, with an initial commitment of about 170 million dollars in FY 1968.

Table 3-4

DECISION POINT 1 SUMMARY

Major Items of New Equipment	No. of Manned Missions	Cost ($B)			Performance			Exploration Period
		Non-Recurring	Recurring	Total	No. of Saturn V Launches	Surface Scientific Mass (kg)	Surface Scientific Mhr	
111% Saturn V Augmented LM Augmented Logistics LM Local Scientific Survey Module	7 (including three orbiters)	0.9	5.9	6.8	12 (includes one test launch)	4,000	400	1971 to 74

3.2.2 Decision Point 2

This decision point is the most important of the three decision points identified since it presents the first opportunity to step up to a capability with potential for extensive lunar surface exploration. Two major options are available: (1) continue at the S/AA level of locale type exploration, or (2) commit funds for new equipment to provide a capability at the medium level for extensive traverses.

Program Options and Funding. Table 3-5 presents a summary of program data relevant to the 6 yr following introduction of the new hardware. At the medium level, a conservative approach to crew return was assumed, and an additional crew pickup launch was used for mission times in excess of 14 days. Six manned missions are associated with each option at a total cost of approximately 5 billion dollars and a funding level of about 1 billion dollars per year in each case. However, a marked improvement in the operation performance is evident when the medium capability is utilized rather than continuing at the S/AA level. Associated with the greater scientific manhours (factor of 8) and scientific mass (factor of 9) achievements, is an increase in the depth of scientific investigation. This additional penetration is represented by the use of the 300-m drill, more extensive seismic experimentation, increased replications of experiments and greater surface coverage.

Table 3-5

DECISION POINT 2 SUMMARY

Major Items of New Equipment	No. of Manned Missions	Cost ($B)			Performance			Exploration Period
		Non-Recurring	Recurring	Total	No. of Saturn V Launches	Surface Scientific Mass (kg)	Surface Scientific Mhr	
Medium Capability Lunar Logistics Vehicle (LLV) Large Rover + Trailer 300-M Drill	6	1.0	4.1	5.1*	17	38,000	5,800	1975 to 79
Continued S/AA None	6	.0	4.6	4.6	18	4,300	740	1975 to 80

*1.4 billion dollars of the total is incurred by the pickup launches.

An anatomy of Decision Point 2 is given in Fig. 3-3 in terms of development schedules and cost for the major items of new equipment associated with the medium-level program. As observed, the commitment of funds is spread over a period of years. In accordance with the guidelines, no commitment to new developments is made until FY 1970. This means that Decision Point 2, at the earliest, falls in CY 1969. An initial commitment of 50 million dollars is required in FY 1970 towards the development of the large roving vehicle, which is the longest lead time item. Peak funding for new equipment occurs in FY 1974 and amounts to about 375 million dollars. A total non-recurring investment of 1 billion dollars is involved.

The important conclusion to be drawn from the analysis of Decision Point 2 is that considerably greater potential for scientific return can be expected in return for a commitment to the medium capability equipment for approximately the same total cost and annual funding level than a continuation of the program at the S/AA level would entail. Further, since the funding commitment to new equipment occurs over a period of 7 yr, this improved performance can be achieved at a relatively low investment risk.

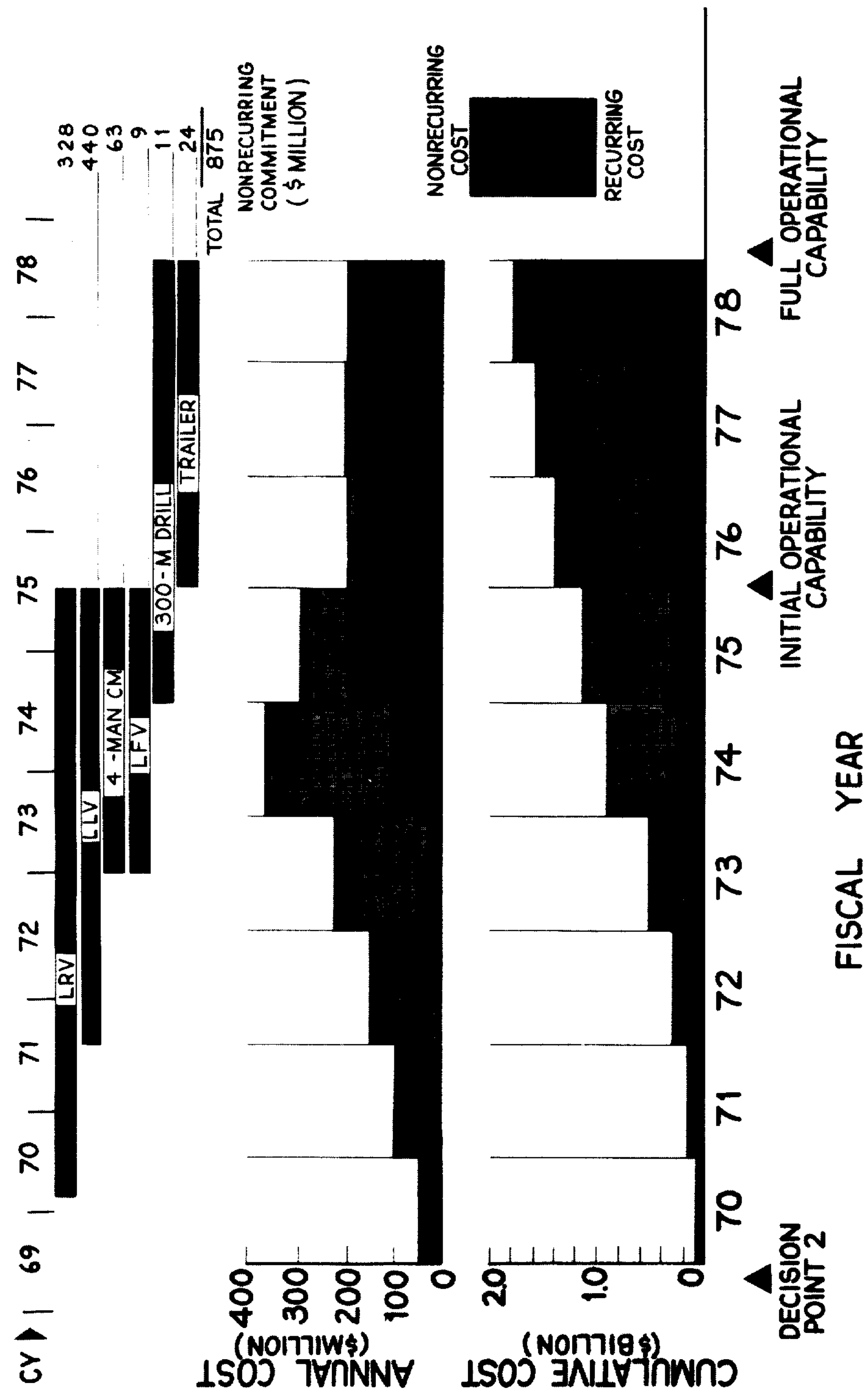


Fig. 3-3 Anatomy of Decision Point 2, Medium-Level Program

Effect of Delay. The data given in the preceding paragraphs were predicated on a decision point occuring in CY 1969. Utilization of the more capable equipment displayed a potential for the accomplishment of 5,800 surface scientific manhours between 1974 and 1980. The influence on cost of delaying Decision Point 2, assuming that exploration continues at the S/AA level during the period of delay, is given in Table 3-6.

Table 3-6

EFFECT OF DELAY OF DECISION POINT 2 – COST TO ACHIEVE 5,800 POST-APOLLO SCIENTIFIC MANHOURS

FY of Decision	Cost Increment ($B)[a]
1970	0.0
1971	0.3
1972	1.25
1973	2.2
1974	3.4
1975	4.4

(a) For delaying a decision to step up to medium capability; exploration continued at S/AA level during delay.

3.2.3 Decision Point 3

The options available at Decision Point 3 are (1) continue at the medium level and,with the introduction of a few additional equipment items, extend the scope of the lunar exploration objectives to extralunar investigations with a medium level (six-man) semipermanent observatory, or (2) increase the scope of exploration through the introduction of large capability equipment and establish an agressive attack of the extralunar goals associated with lunar exploration. Consider a 12-man lunar observatory for an open-ended, semipermanent investigation.

Table 3-7 summarizes data for the alternate programs resulting from Decision Point 3 for the time period 1980 to 90. Maximum funding rates are about 1.5 billion dollars per year.

Table 3-7

DECISION POINT 3 SUMMARY

Major Items of New Equipment	No. of Manned Missions	Cost ($B)			Performance			Exploration Period
		Non-recurring	Recurring	Total	No. of Saturn V Launches	Surface Scientific Mass (kg)	Surface Scientific Manhours	
Continued Medium Six-Man Shelter Nuclear Supply Radio-, X-Ray-, Optical Telescopes	9	0.9	11.0	11.9[a]	50	199,000	50,000	1980 to 89
Large Capability[b] 188% Saturn V Six-Man, Direct Personnel Delivery System Six-Man Shelter Nuclear Supply Radio-, X-Ray-, Optical Telescopes	8	2.8	8.2	11.0	34[c]	243,000	91,000	1981 to 88

(a) 2.1 billion dollars of the total is incurred by pick-up launches.
(b) Large capability systems include a 2-stage LLV utilizing the stage developed for the medium capability logistics vehicle.
(c) Includes two test launches.

The increased investment in the large-capability systems results in considerably greater potential for lunar exploration as can be seen in a comparison with the continued medium level. This is evidenced by the larger scientific mass capable of being transported and utilized and by the significant increase in potential manhours available for lunar science.

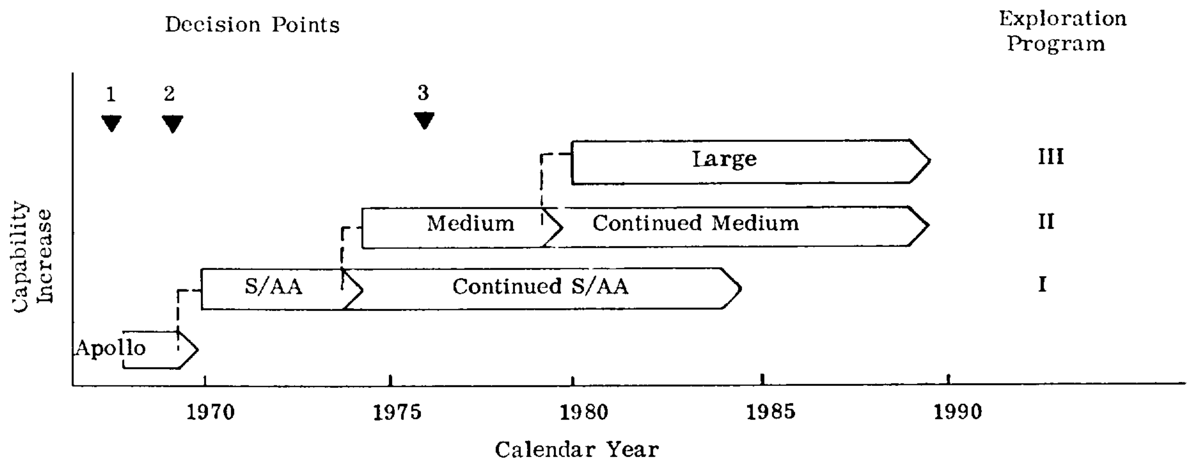
Commitments to either option occur over a period of about 8 yr. Decision Point 3 occurs in 1976. This date ensures maximum usage of the developed medium equipment, is compatible with present predictions for the manned planetary program (which might also require the large Saturn V), and can be accommodated within the guideline funding constraints.

3.3 POTENTIAL EXPLORATION PROGRAMS

The recommended plan for lunar exploration, presented here advocates not a single program with a single set of hardware but a number of program alternates stemming from management options at three key decision points to be encountered over the next 10 yr. The resulting lunar exploration program will depend on the specific decisions made and the timing of those decisions. Table 3-8 summarizes three examples of the types of programs that could result from the alternate decisions analyzed in MIMOSA and discussed herein.

Table 3-8

SUMMARY OF EXAMPLE LUNAR EXPLORATION PROGRAMS



Program Parameter (Post-Apollo)	Program		
	I	II	III
General			
Program Start Date	1971	1971	1971
Program End Date	1984	1989	1988
Number of Missions	27	34	34
Number of Manned Surface Missions	14	18	18
Total Manhr on Surface	18,000	188,000	306,000
Total Mass Delivered to Surface (kg)	132,000	469,000	608,000
Maximum Surface Crew	2	6	12
Science Accomplishment			
Science Manhr – Surface	2,200	56,000	97,500
Science Manhr – Orbit	2,000	2,000	2,000
Science Manhr – Base	0	41,000	86,000
Science Mass – Surface (kg)	17,000	241,000	285,000
Science Mass – Orbit (kg)	5,500	5,500	5,500
Number of Extended Bases	0	1	4
Traverse Range (km)	3,100	9,700	14,700
Resource Allocation			
Number of New Equipment Starts	11.0	24.0	29.0
Total Saturn V Launches	45.0	79.0	63,0
Total Program Cost ($B)	14.8	23.8	22.9
Nonrecurring Cost ($B)	0.9	2.8	4.7
Recurring Cost ($B)	13.9	21.0	18.2

Chapter 4
SIGNIFICANT RESULTS

The MIMOSA planning methodology is an efficient working tool for providing well substantiated answers to lunar exploration planning questions. As such, it represents a valuable aid to NASA program planners. The tool provides a standard logic for lunar program generation and analysis. Mechanization of data handling, routine calculations, and data presentation is achieved through use of a thoroughly checked computer program. The methodology has been developed in such a way that the planner is always in the analysis loop and can make decisions from the data presented. In addition to developing this planning tool, the MIMOSA study illustrated that the methodology could be used in a meaningful manner.

Many of the results derived during the MIMOSA study are dependent on original assumptions. Such assumptions, of course, are governed by the planning environment and represent some of the very parameters that the MIMOSA tool is intended to study. For this reason, the significant results presented in the following paragraphs should be interpreted in the light of the MIMOSA groundrules related to:

- Science – Basic goals as currently conceived by the scientific community with emphasis on geology early and astronomy later
- Funding – Continuous at 1 billion to 2 billion dollars per year
- Launch Rates – modest, three to four per yr initially and six to eight per yr later
- Equipment – Maximum use of Apollo technology, evolutionary development of capability
- Operations – Emphasis on manned exploration and traverse-type investigations

A summary of major conclusions drawn from the MIMOSA study follows.

4.1 INFLUENCE OF SCIENCE

- The achievement of geoscientific goals of lunar scientific exploration calls for the performance of experiments at widely separated surface locations. These experiments are best accomplished by performing long traverses over the lunar surface.
- The performance of active seismology experiments requires delivery of substantial amounts of chemical explosives, which amounts to about 20 percent of the total mass of scientific equipment delivered to the Moon during an exploration program.
- Earth return-mass requirements (scientific samples, films, etc.) are considerable: for the integrated scientific program, the return mass requirements exceed the projected Command & Service Module (CSM) capabilities by a factor of 6. A critical review of the basis for these requirements is indicated and, if the requirements are realistic, subsidiary techniques for improving Earth return mass capability should be developed.
- Generally, the fulfillment of scientific manhour requirements is more difficult to achieve than the fulfillment of scientific mass requirements. This fact is particularly relevant to the early phases of exploration.
- For the scientific programs developed in MIMOSA, geology and astronomy experiments provide over 90 percent of the scientific mass requirements and over 80 percent of the scientific manhour requirements.
- The size of the scientific program to be attempted strongly influences total exploration-program costs. For three typical scientific programs considered in MIMOSA (Programs A, B, and C) the resulting scientific manhours are in the approximate ratio 8:4:1 and the most economical associated program costs are approximately 2.5: 1.5:1.

4.2 EXPLORATION EQUIPMENT

- A modest equipment inventory permits extensive lunar exploration.
- The use of an efficient logistics delivery system is an important factor in reducing total exploration cost. In particular, the direct lunar logistics vehicle (LLV) shows significant cost and performance advantages over the unmanned logistics version of the LM descent stage (LM/Truck).

- Only a modest uprating of the Saturn V launch vehicle will be required for lunar exploration. Generally, requirements are for a launch vehicle with a capability in the range of 111 to 125 percent of the standard Saturn V rating to be introduced in the early 1970's. More extensive upratings can only be used efficiently if long-term bases are assumed. Critical uprating requirements arise from personnel delivery considerations.
- A large roving vehicle with a range of about 800 km is required in the mid-1970's to enable long traverses to be accomplished with a "mobile base." Considerable advantages (in range capability and program cost effectiveness) can be gained by supplementing the basic rover by means of a trailer. Such a combination could be developed to satisfy traverse requirements of up to 1,500 km that result from the MIMOSA scientific programs. The roving vehicle should accommodate at least three scientist/astronauts.
- The main requirement for a lunar flying vehicle arises from a likely need to visit places that are inaccessible to surface rovers in support of scientific observations. A one-man flyer ("pogo-stick") with a range of 7 km should suffice.
- Large (six-man) shelters and nuclear power stations are not required until 1980 or later.
- The choice of cost-effective exploration equipment for the post-Apollo era is not affected by the eventual scope of scientific activity associated with lunar exploration, over the range of programs examined in MIMOSA (this range encompases scientific programs as austere as 3,000 scientific manhours and as abundant as 100,000 scientific manhours).

4.3 OPERATIONS

- Post-Saturn Apollo Applications (S/AA) surface manning levels required for the exploration programs derived in the MIMOSA study are three men in the 1970's and six to twelve men in the 1980's.
- Three-man Lunar Orbit Rendezvous (LOR) delivery techniques can be utilized through the 1970's; six-man direct-delivery techniques can be used efficiently in support of extended bases in the 1980's.

- The program cost penalty associated with use of separate launches for crew pickup justifies a concerted effort toward developing a long-term deactivated CSM for lunar orbital storage during long staytime lunar-surface missions.

4.4 PROGRAM AND RESOURCE

- Three key decision points, regarding commitment to new capability developments will be encountered approximately during 1967, 1969, and 1976 in a nominally paced exploration program.
- Limited lunar exploration through 1984 can be conducted at the S/AA capability level for approximately 1 billion dollars yearly funding and a 15 billion dollars total program cost.
- Extensive lunar exploration through the late 1980's is possible with uprated systems for essentially the same yearly funding rate of 1 billion dollars and at a total cost of approximately 23 billion dollars.
- The nonrecurring costs associated with these programs are relatively small and amount to 1 billion dollars for the S/AA systems and from 2.8 billion to 4.7 billion dollars for the two alternatives, identified in the recommended plan, that use the uprated systems.
- The sensitivity of the program resource demands to selection of the Earth-to-Moon transportation systems can be clearly understood from the distribution of total program cost by equipment category observed in the program resource results:
  - Transportation System – 80 percent
  - Mission Equipment – 10 percent
  - Major Scientific Equipment – 4 percent
  - Other (integration, minor science, etc.) – 6 percent
- Extensive lunar exploration can be conducted at a funding rate of about one-third the present manned space flight budget and at a total cost approximately equal to that commited to Apollo.